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SIMULATION OF FOREST INSECT PEST MANAGEMENT

D. Gordon Mott

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SIMULATION OF FOREST INSECT PEST MANAGEMENT

D. Gordon Mott

INTRODUCTION

Interaction with a computer in a time-sharing environment permits the user to perform calculations in a variety of unique ways. Among these are simulations of the dynamic behavior of systems of concern to the user, together with the opportunity to perform control or regulatory actions during the simulation. In jargon, the user is permitted to play "what if?" This capability permits experimentation with a numerical representation of a real system rather than with the system itself. As a result, experiments can be conducted on the computer which would be impossibly expensive with the real system, or take generations to complete (as in the case of most natural resource systems), or which would be extraordinarily hazardous.

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Interestion will a computer in a time-charing management sensits the mean to perform colourations in a variety of unique unys. Among them are simulations of the dynamic behavior of systems of concern to the mean, begather with the coperturity to perform control or regulation solitons during the simulation. In tempoh, the ware in permitted to play which if "his capability permits experimentation with a meanical representation of a usel system rather that with the apparatus that the computer which the results apparatus with the capability of the treation of the computer apparatus to the impossibly experiments can be conducted on the computer momental to the impossibly experiments with the real system, or take a which would be extraord to the case of note matural resource systems).

There is another valuable aspect to simulation programs -- they permit the programmer to summarize his view of the real system and transmit it to another person in a form which is far more effective than either the written or spoken word -- the material which is communicated can be used and manipulated by the second person, and thus absorbed through direct experience. This is the principal intent of the present program -- to communicate to those concerned with regulating natural pest populations, some of the structure which must be provided in making management decisions. A knowledge of the dynamics of the managed pest population, the field effectiveness of the control material, the effect of the pest on the production of host values, and the economic framework within which decisions must be made, are some of the aspects of decision making that are to be considered. It is generally true that for a variety of reasons, forest pest management is not based upon an adequate knowledge of any of these, and forest pest research is not adequately funded to produce the required knowledge. In a very real sense, the author is playing "what if?" -- he is trying to communicate to the present reader what could be done if there was sufficient knowledge available. In order to do so he has brought together a number of elementary considerations with the intention of illustrating the existence of an opportunity to elevate the standard of practice in the field.

communications device. What is to be communicated will become clear below. At this point it is very important that the reader/user realize what is not to be communicated. The program does not produce simulations for any actual events. No result is represented as being realistic. There are several places in the text where a relationship is suggested between the results or structure of the program and certain real situations. In no such case is it being suggested that there is detailed structural agreement with the real case, nor that the program as a whole approximates any real case. In other instances, comments are made which reveal the nature of the discrepancy between this simulated program and certain known features of a real situation. In brief, whatever the merits of this program, it is not designed to obtain solutions to real problems.

Patennesses with a program is intended by an a stone derice of Mart is to be communicated will because stone derice is to very issuantent that the standard of this point is in not to be communicated. The program simulations for any several events. To result is the being realistic, There are several places in the complete realistic, There are several places in the program and certain tend estimations. In so one it being suggested that there is detailed structural serent end other inches one other inches the program and certain other inches the program as a whole as contends of the diameters that there is detailed structural communication of a real attention. In brund, whatever the certain

Description of Program

General

The simulation contains four major elements:

- (1) a simulator for the dynamics of the pest population.
- (2) a relationship between pest population density and intensity of damage.
- (3) a control "device".
- (4) a cost-benefit analysis.

There are three population dynamics models, four damage functions, and two control procedures. Each is discussed below in detail. It is possible to choose 24 different combinations of population dynamics models, damage functions, and control procedures.

The parameters of each population dynamics model are fixed.

However, some of those of the damage functions and the control devices are variable, so that the user can actually explore a very much larger number of situations than the 24 mentioned above.

The program is written in 360-Fortran IV and uses a plotting subroutine developed at the Yale Computer Center for typewriter terminal plotting. A 132 character terminal is necessary.

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Population dynamics simulation

There is a choice of three different population dynamics simulators -- one which produces an oscillating density over time, and two which produce stable densities.

The oscillating model consists of the difference equation:

 $\log N_{t+1} = C_0 + C_1 \log N_t + C_2 \log N_{t-1} + C_3 \log N_{t-2}$ where: N_j = Pest density in generation j. $C_i = Constant$

This model produces an oscillation in density from about 1×10^3 to about 6×10^6 . If initial conditions outside the normal population cycle are specified, transient conditions may exceed this range. The model was derived from an analysis of actual pest density data in which density in previous years affects the rate of change in density in the current generation, because there are lag effects in the system. One of these was speculated to consist of deterioration in the nutritional quality of current foliage when defoliation has occurred in previous years. Others probably consist of the normal lag in parasite, predator, and disease effects in such systems.

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-- one which produces an escillating density over time,
aich produce stable densities.

escillating model emuists of the difference corelamn

= $C_{p}^{p}C_{1} \log R_{s} + C_{2} \log R_{s-1} + C_{3} \log R_{s-2}$ $R_{j} = \text{Pest density in generation j.}$ $C_{1} = \text{Constant}$

no model produces an carillation density from about I x luters of a 10°. If initial combitions outside the normal hopulation openified, translant conditions may exceed this range. The sease derived from an analysis of nothers post density data in which a provious posts affects the rate of change in density in the generation, because there are highertrate in the appealance of consists of deletionalism in the appealance of consists of deletionalism in the natritional seases appealanted to consist of deletionation in the natritional of constant probably consist of the normal lag is persiste, smelther

The model oscillates with a period of about eight years. A typical pattern is depicted in Fig. $1.\frac{1}{}$

 $\frac{1}{2}$ Hint: The system posseses an equilibrium point at

$$\log N_e = \frac{C_0}{(1-C_1-C_2-C_3)}$$
 where

$$C_0 = +2.615$$

$$C_1 = +1.454$$

$$C_2 = -0.978$$

$$C_z = -0.0173$$

Figure 1.--Logarithm of pest density over time as generated by the oscillating population dynamics model.

There are two different stable models, one based upon an exponential density-dependent rate of change, and one based upon a sigmoid (logistic) model for the same process. In both cases it is assumed that:

$$N_{t+1} - R_{t} N_{t}$$

where R represents the net rate of population change in generation t.

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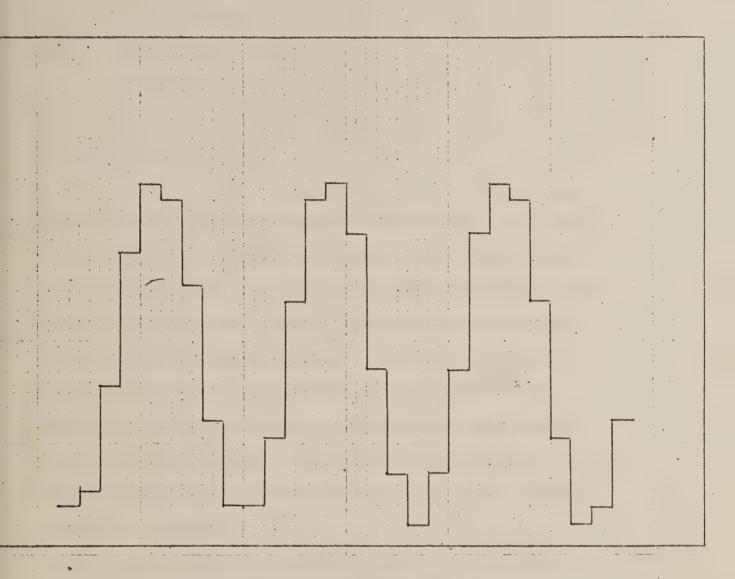
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Time

Figure 1.--Logarithm of pest density over time as generated by the oscillating population dynamics model.



In the first case (see Fig. 2):

$$R = C_e^{**}(-aN_t)$$

where: C = Maximum R = 2.5

$$a = .9163 \times 10^{-5}$$

These values of C and a have been chosen in order to give a stable density at 100,000. The equilibrium point in this system (where R = 1) is at N = ln C/a. The time trajectory through which density moves to the equilibrium value, given an initial condition elsewhere, depends upon other properties of the relationship. However, this function has been chosen to represent a case in which R, the capacity of the pest to increase, increases (to an upper bound) as pest density is reduced. That is, a higher percentage control will be needed to maintain density at a value lower than 100,000, as density is reduced.

Figure 2.--Density dependent population change function used in the exponential population dyanmics model

$$R = Ce^{-aN}t$$

$$C = 2.5$$

$$a = .9163 \times 10^{-5}$$

^{**}designates exponentiation

value of the equilibrium point in this system (where R = 1)

y of 100,000, The equilibrium point in this system (where R = 1)

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a = .9163 x 10

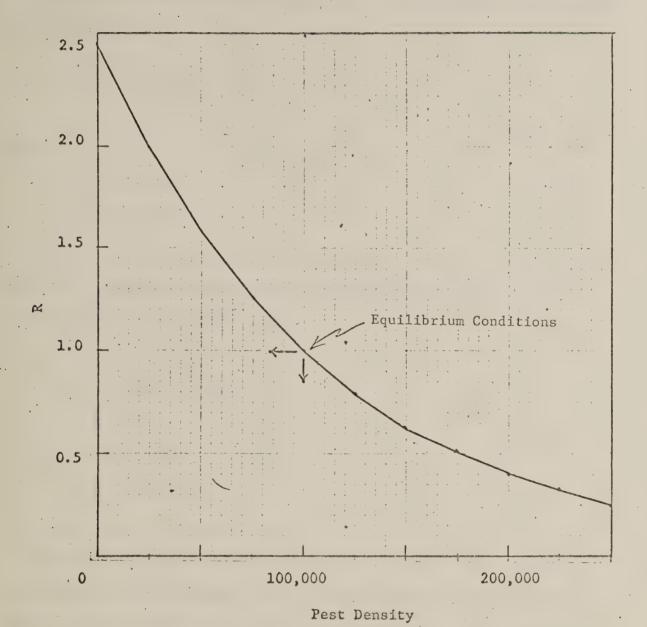


Figure 2.--Density dependent population change function used in the exponential population dynamics model

$$R = Ce^{-aN}t$$

$$C = 2.5$$

$$a = .9163 \times 10^{-5}$$

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the exponential population dynamics model

R = Ce L

C = 2.5

e = .9163 a 10

The second stable relationship (Fig. 3) is based upon the logistic function in which:

$$R = \frac{C}{1 + e^{**}(a + b/N_t)}$$

where:

$$C = 5.0$$

$$a = 2.197$$

$$b = -81093.0$$

Figure 3.--Density dependent population change function used in the logistic population dynamics model.

$$R = \frac{C}{1 + e^{**}(a + b/N_t)}$$

C = 5.0

a = 2.197

b = -81093.0

This system again has a stable equilibrium point at N = 100,000. It differs from the previous system in that R behaves differently as density changes, and thus the same control method will be found to be optimal at a different density than in the previous system.

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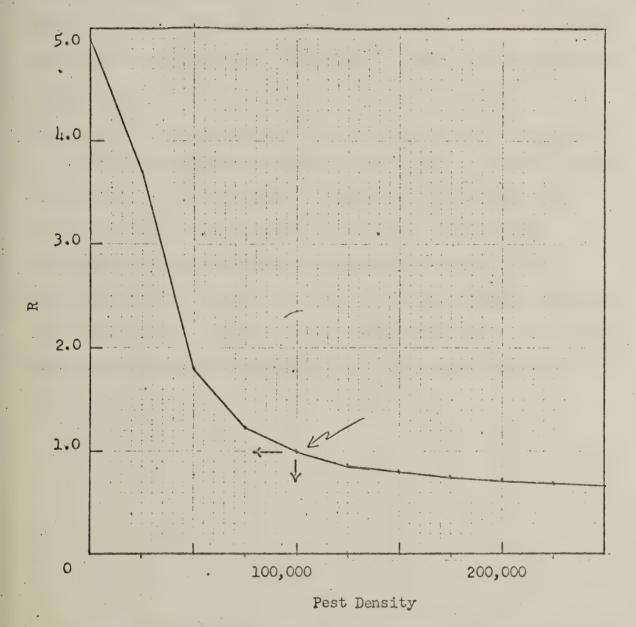


Figure 3.—Density dependent population change function used in the logistic population dynamics model.

$$R = \frac{C}{1 + e^{**}(a + b/N_{t})}$$

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$$a = 2.197$$

$$b = -81093.0$$

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3. Donairy dependent population change function used

o logistic grow titon dynamics model.

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The time trajectories through which population density moves towards the equilibrium value for each of the two stable models are shown in Figure 4.

Figure 4.--Time trajectories of pest density (initial number = 1000)

according to the exponential and logistic, stable population dynamics

models.

Both of these systems approximate some general population change characteristics of real systems in that they exhibit a maximum rate of change, and an asymptotic approach to a minimal rate.

The assumption that the R function depends upon density is an elementary realistic one in many cases, although somewhat controversial as a general case. In fact, the assumptions throughout this program that the relationships are deterministic, are somewhat naive and elementary.

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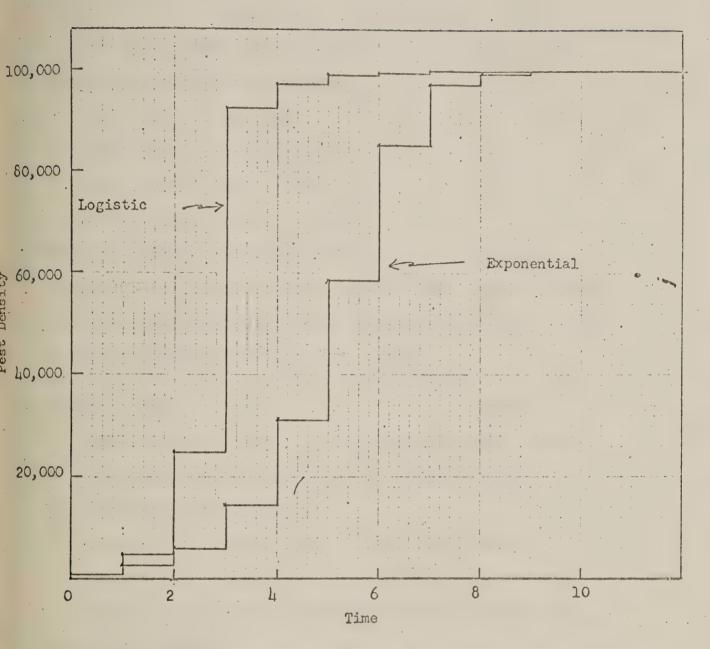


Figure 4.--Time trajectories of pest density (initial number = 1000)

according to the exponential and logistic, stable population dynamics

models.

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error A.-- Plans trajectories of post density (isitial number = 1830)

Pest Density - Damage Functions

One of four different relationships between percentage host damage and pest density can be chosen:

(1)
$$D = 100 (1 - 10**-aN)$$

(2)
$$D = 100 (1 - 10**-a log N)$$

(3)
$$D = 100/(1 + 10**a + bN)$$

(4)
$$D = 100/(1 + 10**a + b \log N)$$

Where D = percentage of complete damage, and N = pest density.

(Functions 2 and 4 can be stated in simpler terms, they are presented this way to show their relationship to functions 1 and 3.) The forms of these functions are shown in Figs. 5 and 6.

Figure 5.--Damage

Damage functions 1 and 2. In each case the density at which 90 percent damage occurs is specified by the user, and the value of a calculated in the program.

Function 1: % Damage = 100. [1 - 10**(-a x density)]

Function 2: % Damage = 100. $[1 - 10**(-a \times log density)]$

The pest density scale is the same as that in Figure 6 for comparative purposes.

Figure 6.--Damage functions 3 and 4. In each case the densities at which 10 percent and 90 percent damage occurs are specified by the user.

Function 3: % Damage = $100/[1 + 10**(a + b \times density)]$

Function 4: % Damage = $100/[1 + 10**(a + b \times log density)]$

The pest density scale is the same as that in Figure 5 for comparative purposes.

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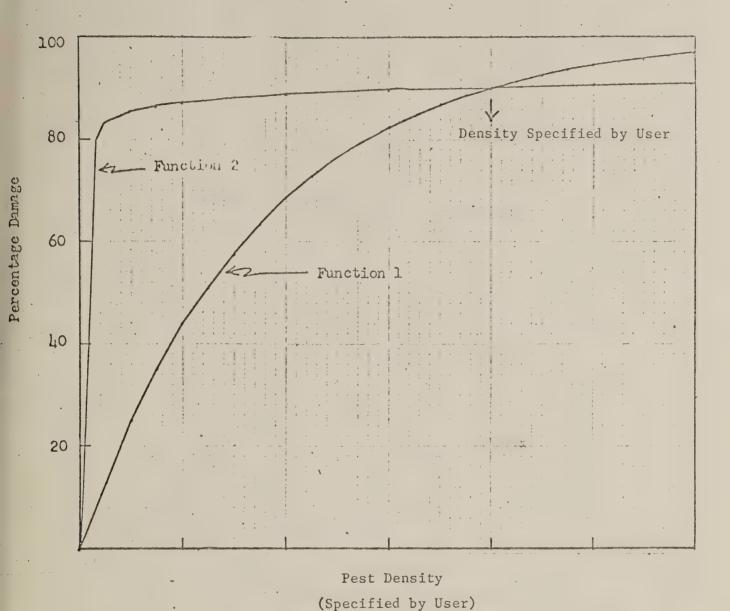


Figure 5.--Damage functions 1 and 2. In each case the density at which 90 percent damage occurs is specified by the user, and the value of a is calculated in the program.

Function 1: % Damage = 100.[1 - 10**(-ax density)]

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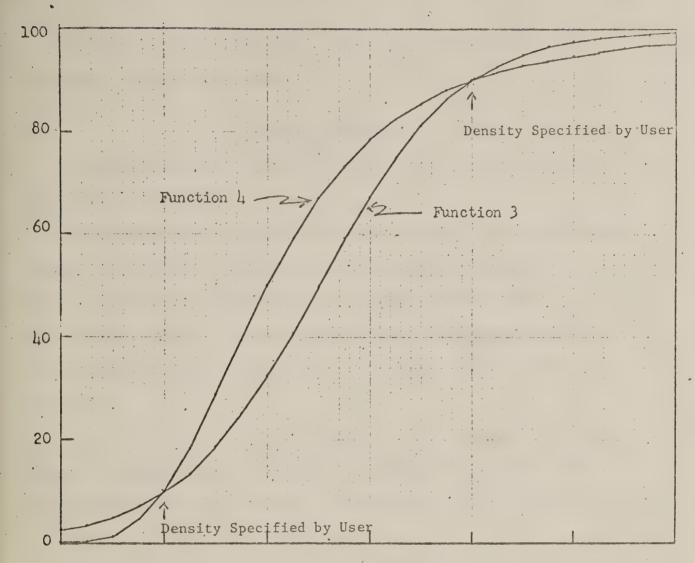
The pest density scale is the same as that in Figure 6 for comparative purposes.

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Function 1: I Damage = 100.[1 · 0**(-a denotion)]
Function 2: I Dama = 100.[- 10**(-ax log densit)

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Pest Density
.(Scale is Specified by User)

Figure 6.—Damage functions 3 and 4. In each case the densities at which 10 percent and 90 percent damage occurs are specified by the user.

Function 3: % Damage = 100/[1 + 10**(a + b x density)]

Function 4: % Damage = 100/[1 + 10**(a + b x log density)]

The pest density scale is the same as that in Figure 5 for comparative purposes.

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6.-Demage functions 3 and 4. In each case the densisize at 10 percent and 90 percent damage occurs are openified by the

Punction 3: 1 Damage = 100/[1 + 1000(a + b x log d.asfty)]

Function 4: 1 Damage = 100/[1 + 1000(a + b x log d.asfty)]

s past density scale is the same as ther in Figure 5 for comparations

In each case, the parameters a and b are selected by the user (see below: "Using the program").

Control Procedures

Two different kinds of control are provided: an insecticide, and sterile male release.

The insecticide is assumed to possess a typical sigmoid relationship between the percentage mortality procuded, and the logarithm of dosage applied. A logistic function is used to describe the relationship (Fig. 7). Its parameters are derived from specification of the LD50 and LD95 of the material, in response to a query from the program.

Figure 7.--Dosage-response function for effect of insecticide. The curves exhibit the same LD50 of 2, and different LD95's of 10 and 20.

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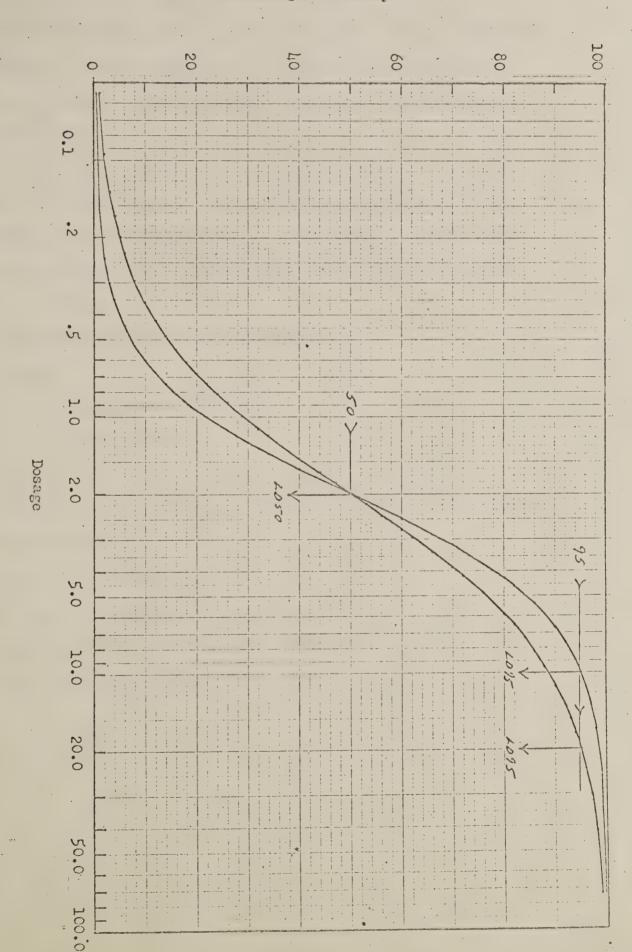


Figure 7.--Dosage-response function for effect of insecticide. The curves exhibit the same

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The sterile-male control procedure is assumed to have an effect directly proportional to the proportion of sterile males in the male population. The male population is assumed to be one-half of the total population. A "dose-response" relationship for this approach is shown in Fig. 8.

Figure 8.--"Dosage-response" relationship for sterile male release.

Percentage "mortality" obtained from given values of sterile male/
population ratios (S/D), assuming fully competitive sterile males,
and a .50 sex ratio.

Percentage mortality = 100 S/[(D/2),+ S]where,

S = number of sterile males

D = pest density

In each case, the effects of the control procedure are assumed to be as follows:

 $N_{t+1} = (1 - PM/100) N'_{t+1}$

where N_{t+1} = actual number in next generation.

 N'_{t+1} = predicted number in next generation.

PM = percentage mortality from control.

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tion. A "dose-response" relationship for this appraisels in Fig 8.

e 8.--'Do: age-response' relationship for exerite nulc valence.

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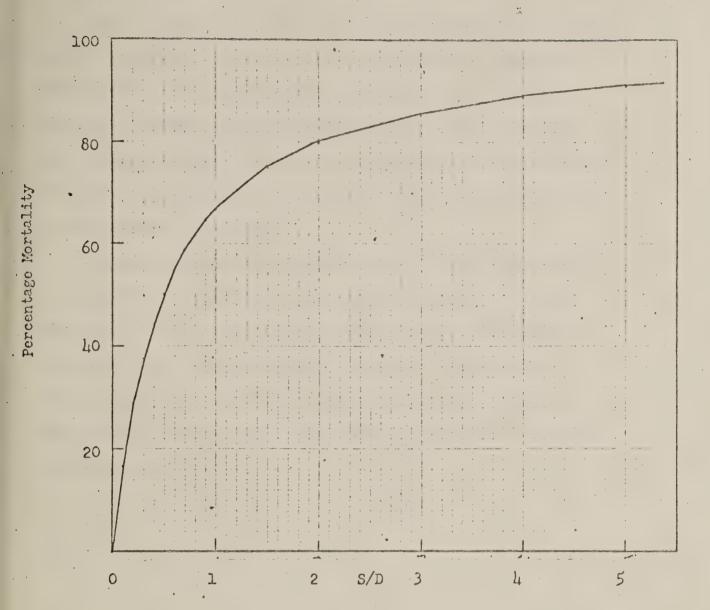


Figure 8.--"Dosage-response" relationship for sterile male release.

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D = pest density

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Rights B.-- "Dozaga-verpones" relationship for atorila mala melessa.

atage "mortality" obtained from given values of sterila sale/population ratios (S/D), assuming fully compatitive starila male, and a .50 sex ratio.

- Percentage mortality - 100 8/[(D/2) + 8]

Thus, no provision is made for such known effects as increased natural survival in the remainder of a generation to compensate for control-induced mortality within the generation, as a result of density-dependent survival phenomena in the system. Instead, this assumption yields the result that is usually naively expected in control operations -- a degree of reduction in pest density equal to that obtained by control.

The user is permitted to choose whether he will always apply the same level of control, or will select a unique level in each generation. In the case of sterile male control, he is permitted to specify a percentage mortality (the program then calculates dosage as the number of sterile males released), or to specify the number of sterile males to be released (the program calculates percentage mortality).

3: no provided in mode for such known affects us increased vival in the remainder of a generation to compensate control-induced mertality within the generation, as a result y-dependent survival phenomena IN the system. Instead, a suspiner yields the result that is usually calvely expected nered appentions - a degree of reduction in post density equal obtained by control.

user (see multied to choose whether he will stroys opply level of centrel, or will salect a unique level [3] early ion. In the cree of sterile male centrel, [4] is permitted pectify a percentage mortality (the program then calculated as the number of sterile males released), or to specify of sterile males to be released (the program calculates age mortality).

Cost-Benefit Analysis

The program calculates the benefits derived from control activities on two different bases, termed short term and long "Short term" gains and benefits (gain minus cost) are calculated from current control costs, and the difference between the value of actual damage, and that to be expected from the current uncontrolled predicted pest population. "Long term" gains and benefits are calculated from the current control costs (as above) and the difference between the value of actual damage, and that to be expected if no control activities were ever carried out. These two calculations are needed, because, for example, certain control activities will result in higher average damage over the long term, even though they result in positive gains in the year in which they are conducted. This phenomenon can be seen most easily in the case of the oscillating model. On the other hand, certain control actions will have the opposite result -- over the long term, average damage is reduced even where there is a net loss in the year of the control activity.

In detail, cost, gains, and benefits are calculated as follows. Whenever a control action is taken, it is assumed that a fixed cost (FIX); and a variable cost, the cost per unit of the control material (VAR) multiplied by the number of units used (DOSE), are incurred. Thus,

COST = FIX + VAR.DOSE

When no control action is taken (percentage mortality = 0) no cost is incurred.

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(FI: ; and a variable cost, the cost per unit of the control

11 (VAR) multiplied by the number of units used (DOSE), are

T = F X VAR. DOSE

Common action is taken (percentage mortality - 0) no cost

The gain in value as a result of control action (VGAIN), is calculated by subtracting the value of the percentage damage actually obtained from that expected if no control action were taken. Short term and long term gains are each calculated as described above, using the two different pest densities for calculations of expected damage.

The concept of the value of damage is purposely left very general. The user determines what value he will place upon 100 percent damage -- it can be the value of a year's growth reduction, the value of an aesthetic impact, the value of a crop destroyed, or any combination of these. Within the concept of this program; this does not matter. Something that does matter, however, is that no provision is made for the effects of damage to compound. That is, in real forest systems, one expects that in some cases severe defoliation, say, in two or three consecutive years in a decade will have a more severe impact than the same severe damage separated by years of light damage in which growth recovery takes place.

Similar remarks might be made concerning the costs of a unit of control material. It is not intended that this should be simply the cost of treating with say, one pound of material per acre. The user can decide whether more general environmental costs are also to be included. 2/ However, in this case again, no provision has been

2/ Consideration was given to including constraints on the amount of any toxic material used. However, while this sort of restriction must be involved in any real case, the purposes of this program do not require it.

made for say, compound effects from the accumulation of toxic material in the environment.

Finally, no provision has been made for compounding interest on either the costs of control or the value of gains. This would also be required in any real analysis, as would provision for rising trends in costs and values in an economic projection.

Using the Program

The basic program format consists of a series of inquiries from the program concerning the values of parameters and choice of functions. The user responds to the inquiries, and, given a complete set of input data, the program performs the simulation and writes a report on the results. Tables 1 to 9 contain the results of sample sessions. The following discussion is organized around each of the inquiries.

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Finally, no provision has seen or or the value of galas. I fred in any real analysis, as would provision walves in an economic projection.

ics opposent format consists of a series of inquiries from east on erning the values of parameters and choice of functions. respond to the inquiries, and, given a complete set of input rogrum a forms the simulation and writes a report on the form the results of sample sessions. The

Firstly, the program edits all input information and issues error notifications where they are appropriate. These are all self-explanatory and since it is anticipated that the user will have no difficulty responding to them, they will not be discussed in detail.

There is one general feature to be noted before proceeding with the discussion -- all inquiries which require a numerical entry, will require positive values. If a negative value is given (for example, a negative number of generations, or a negative initial density) the program will return to the beginning (the third inquiry). This permits the user to change her/his mind before entering the simulation. (Ordinarily, time-sharing systems provide for cancelling an input line before transmitting it to the system; this provision permits in addition, modification of previously entered material.)

After testing for negative entries, the program also edits the input data for validity in a variety of other ways.

Program Prompts and Inquiries

1. ***POPULATION REGULATION SIMULATOR***

CLEAR TABS AND SET TO 37 (RELATIVE)

The user clears all left tabs on the terminal up to 37 spaces from the left margin. This is for proper alignment in the output table when unique control rates are entered in each generation.

The program will inquire:

each tip input information and issues

each tip charteness the the user will have no
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expression them, they will not be dismassed in detail,
the is one general feature to be noted before proceeding
to liscussion -- all inquiries which requires a numerical entry,
the involves. If a negative value is given (for
les, a neget number of generations, or a negative initial
ty) the program will return to the beginning (the third inquiry),
tts the user to change her/his aird before entering the
latton. (Ordinarily, time-sharing systems provide for enreality
line before transmitting it to the system; this provision
the in addition, modification of previously entered valueing.)

To validity in a variety of other ways.

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TABS AND SET TO 37 (RELATIVE)

The user clears all left tobs on the terminal up to 37 spaces from the left margin. This is for proper alignount in the output table when unique control rates are entered in each generation.

will inquire:

2. O.K. ?

After each carriage return, until the user replies "YES" (or "Y"), permitting repetitive tries to set tabs. If they have not yet been set, reply "NO" (or "N").

3. SELECT A POPULATION MODEL - OS, LG, EX:

By replying "OS" the user chooses the oscillating population dynamics model; "LG", the logistic, and "EX" the exponential.

4. SELECT A CONTROL SYSTEM - IN OR SM:

"IN" chooses an insecticidal control system; "SM", sterile males.

5. ENTER NUMBER OF GENERATIONS:

Reply with the number of generations for the simulation.

This must be less than or equal to 100. A negative value returns to the beginning of the program, "O" is an invalid entry.

6. If the insecticide control system was chosen the following prompt will be used:

ENTER LD50 AND LD95 OF INSECTICIDE:

These are to be viewed as field values; that is, the number of units of the material as applied in the field necessary to obtain 50- and 95-percent mortality, respectively. From these figures the program calculates the parameters of the log-dose, logistic-response function. O is an invalid entry, as is an LD50 greater or equal to the LD95.

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THET A POPULATION MOUNT OS. LG, EX:

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1 be used:

TER LDSO AND LDSS OF INSECTICIDE:

These are to Ed viewed as field velues; the a, the manuscript of the material as giplied in the fiel' see story to 50-, and 95-percent mortality, respectively. From these the program calculates the parameters of the leg-dess, ite-fished function. O is an invelid entry, as is an monter or equal to the LD95.

7. ENTER FIXED AND VARIABLE COST OF A UNIT OF CONTROL:

Any non-zero numbers are legal entries. Fixed cost is viewed as that cost of treatment which does not depend upon the dosage applied. Variable cost is the cost of applying a unit does (one sterile male in that case; one pound or ounce, or whatever, in the case of insecticide). The costs, in the estimate of the user, can include any relevant values. Zero is a valid entry.

8. WILL YOU APPLY UNIQUE CONTROL IN EACH GENERATION?

Reply "YES" or "NO" depending upon whether you wish to decide upon the control rate after seeing the projections in each generation ("YES"); or to specify in advance that a particular control rate will be used in all generations ("NO").

9. WILL YOU USE A CONSTANT NUMBER OF STERILE MALES?
A reply of "YES" will be followed by:

10. SPECIFY NUMBER OF STERILE MALES TO BE RELEASED EACH GEN:

Any non-negative number is valid.

A reply of "NO" (to inquiry 9) will be followed by:

11. SPECIFY PERCENT MORTALITY IN ALL GENERATIONS:

Any non-negative number is valid.

(A reply to "NO" to inquiry 9 will result in the program calculating in each generation the number of sterile males required to produce the percentage mortality specified in response to inquiry 11. A reply of "YES" will result in percentage mortality being calculated from the constant number of sterile males specified in response to inquiry 10. In each case the calculation produces results which also depend upon pest density.)

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liets' Variable cost is the cost of eggs, ing a unit does not sturile male in that case, one pound or conce, or whateven n the case of insecticide). The cases in the case of insecticide). The cases in the case of insecticide)

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y Reply "YES" or "NO" depending upon whether you wish in dag a the control rate after seeing the projections in each wration ("YES"); or to specify in sevence that a raiselos

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A reply of "YES" will be followed by:

SCIPY NUMBER OF STERLILE MAINES TO BE RELEASED PAGE 15. N.

Any non-negative number is valid.

A reply of "MO" (to inquiry the will be followed by:

Any mon-negative number is velid.

for reply to "MO" to inquiry 9 will feault in the program
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and to the percentage mortality specified in response to
any 11. A coply of "MES" will result in percentage mortality
colculated from the constant number of sterile males
of in response to inquiry 10. In each case the culculation

which elso depend upon past density.)

If the sterile male control system was selected and the answer to inquiry 8 is "YES", the response will be:

12. WILL YOU SPECIFY NUMBER OF STERILE MALES? (NOT % MORTALITY):

If the reply is "YES", the program will take the numerical input demanded during the simulation to be the number of sterile males released in that generation. If "NO", input will be taken to be percentage mortality.

If the insecticidal control system was selected and the same rate of control in each generation was specified in response to inquiry 8 ("NO"), the next inquiry will be:

13. SPECIFY PERCENT MORTALITY IN ALL GENERATIONS:

Any non-negative reply is valid. The program will calculate the dosage of material required to produce this level of mortality. Note that in the case of an insecticide, it is assumed that this dosage is not dependent upon density. (This is a common field assumption which has no validity. It has been shown in many cases that it requires far more material per unit area to obtain the same population control rate where density is low, than where it is high. However, this program does not aim at optimizing field application techniques).

THE S CORPTAL System was selected and the enswers

OU SPECIFY NUMBER OF STERIES MALEST (NOT & MOREAUTY):

it demanded during the simulation to be the number of starils ale; released in that generation. If "MO", input will be taken be percentage mortality.

It the insecticidal control system was selected and the same of control in each generation was specifical in response to aquiry 8 ("NO"), the next inquiry will be:

PERCENT MORTALITY IN ALL GENERATIONS:

An, non-negative reply is valid. The progress will calculate

rtality. Note that in the case of an insectic.de, it Ed assumed this desage is not dependent upon density. (This is a conven assumption which has no validity. It has been shown in wany that it requires far nore material per unit area to obtain e same population control ritu where density is low, than where

it is high. However, this program does not aim at optimizing field

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14. SPECIFY DAMAGE FUNCTION NUMBER AND VALUE OF 100% DAMAGE:

The damage functions are numbered as presented above in the text. Function numbers 1 to 4 are valid entries. The second entry includes all relevant costs (values) associated with 100% damage to the crop.

If damage function number 1 was specified in response to inquiry 14:

15. ENTER PEST DENSITY AT WHICH 90% OF COMPLETE DAMAGE OCCURS:

Any non-negative value is valid.

If damage function number 2 was specified in response to inquiry 14:

16. ENTER LOG PEST DENSITY AT WHICH 90% OF COMPLETE DAMAGE OCCURS:

Any non-negative value is valid.

If damage function number 3 was specified in response to inquiry 14:

17. ENTER PEST DENSITIES AT WHICH 10% AND 90% OF COMPLETE DAMAGE
OCCURS:

Any positive entries in which the second is greater than the first are valid.

If damage function number 4 was specified in response to inquiry 14:

Ty DANISE FUNCTION NUMBER AND VALUE OF 1008 RANAGE:

demagh functions are numbered is presented above in the
netion numbers 1 to 2 are valid entries. The sec

if damage function number 1 was specified in

quitry 14:

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Any non-asgative value II valid.

If lamage function number 1 was specified in response to

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If damage function number I was specified in response to

MIER DEST DEMOITIES AT MIMICH 10% AND 90% OF COMPLEKE PLANCE.

Any positive entries in which the second in greater that the ret are walld.

function number 4 was specified FH response to

Ery : 4:

18. ENTER LOGS OF PEST DENSITIES AT WHICH 10% AND 90% OF COMPLETE

DAMAGE OCCURS:

Any positive entries in which the second is greater than the first, are valid. Note that this restricts the range of pest density over which damage can occur to numbers greater than 1.

The user will find it useful to remember that pest density in the oscillating model (OS) is not normally greater than 10⁷, except under unusual initial conditions and some control regimes. In the case of the stable models (LG and EX), the models produce a steady density of 100,000. The parameters of the damage functions can be chosen to explore a wide variety of damage rates, and consequently, gains and benefits from control, in these population density ranges.

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Any positive entries in which the second is stars the first, are valid. Note he this restricts the range fist density ever which dames tensecur to suchers over

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eady density of 100,000. The na ters'

ius ons can be chosen to explore when yarrets no dan .

Takes, and consequently, tuins an a to from control of

19. ENTER NUMBERS IN FIRST THREE GENERATIONS:

Any positive numbers are valid. The third value is used as the initial value in the stable model simulations, all three are used in the oscillating case. In the latter case, it will be useful to choose as initial values, a sequence of three from a simulation that has run for 20-50 years, in order to examine cases of regular oscillation rather than those with a large transient signal effect.

If unique control was specified in response to inquiry 8

("YES") during execution the program will demand that the

control percentage, or number of sterile males, be entered

after the values of expected density and damage are written.

The inquiry

20. consists of a ">" written under the column heading "CONTROL RATE".

Following entry of the desired control rate, the carriage must be returned. If a negative entry is given, the program returns to the beginning and the current simulation is aborted.

Following completion of the simulation summary, the user is asked:

21. GRAPHS?

A response of "YES" produces three graphs containing:
the logarithms of uncontrolled and actual pest densities over
time, the logarithms of expected and actual pest densities over
time, and uncontrolled percentage damage and actual percentage
damage over time.

Finally, the user is asked:

ENTER MUNICIPAL IN PIRET TRUET CRIMEDIANCES

sitive numbers are valid. If third value is wed us the initial value in the state out number one, sed in the oscillation case, in the latter of the choose as initial values, a sequence: consider that has run for 20-50 years, in order saminates of regular oscillation rather the

If unique control was specified ... exponse

("YES") during execution the prog ..

tentrol percentage, or number of sterils asles are rered

after the values of expected lensity or are written.

The inquiry

consists of a ">" written unner the sent ' and "CONT PATE".

'following entry of the desired control rate, the reason us be returned. If a negative entries given, the or of the semilar or standard a storted.

returns to the beginning and the current standation is aborted.

esnonse of "YES" produces three graphs containing:

oget thms of uncontrolled and actual pest densities over

the oger; hms of expected and actual pest densities over

uncontrolled percentage damage and actual percentage

22. FINISHED?

A reply of "YES" exits from the program, "NO" returns to the beginning for another simulation.

Results

The format of the results produced by the program is illustrated in the tables that follow.

It is intended that questions for exploration be formulated by the user. Consequently, an extensive analysis of results is not offered here. However, examples of the exploration of two typical questions are shown in Table 1 - 4, and 5 - 9.

In the first case, the effects are shown of using sufficient insecticide in the oscillating population system to produce 75, 85, and 95 percent control in all generations (Tables 1 - 3) and the effects of using an undisclosed control strategy on the same system (Table 4).

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orms of the results produced by the progress is libratraged that follow.

that questions for exploration be formulated by a tractly, an extensive analysis of results is not efferted.

The examples of the exploration of two typical questions are in Table 1, and 5 - 9.

first case, the effects are shown of using sufficient cit; in the oscillating population system to produce 75, 35, reent control in all generations (Tables 1 - 3) and the using an undisclosed control strategy on the same system.

Note that total short-term gains decline as increasing control rates are applied, whereas total long-term gains increase and then decrease, revealing that at some point between the 75 and 95 percent control rates there is an optimum level. The results (including other simulations on this same system) are displayed in Fig. 9. It is clear that shortterm gains are maximized between control rates of 50 and 85, if a control strategy is used which applies equal dosages of the insecticide in all generations. It has been shown however in Table 4 that there is some other strategy which produces a better result than any of those used above (it is left to the reader to discover this, or a better one -the author would be interested in hearing about any that are better). It would be unusual to apply at low densities when little or no damage is expected. The usual procedure is to try to control under circumstances which produce short-term benefits -- this is left to the user to explore. It might be interesting to contrast the effects of controlling only at high density with those of applying control at moderate, increasing densities and moderate, declining densities. Although the results of these simulations should not be taken seriously, there are some which are worth contemplating in real systems.

Figure 9.--Short-term benefits (n) and long-term benefits (.) in a particular simulation (see text) as control rate in the generation is varied.

Note that short- and long-term benefits are optimized at different control rates.

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t short - and long-term benefits are optimized at different

Figure 9.--Short-term benefits (x) and long-term benefits (•) in a particular simulation (see text) as control rate in the generation is varied.

Note that short- and long-term benefits are optimized at different control rates.

9. --Shore-term benefits (x) and leng-term benefits (*)

la 2 particular simulation (see text) as control rate in the

Note that hort- and long-term benefits are opsimized at different

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If the user conducts other simulations on the same system, allowing the value of damage, and the pest-density damage function to vary, he will discover how important it is to have a detailed knowledge of the exact nature of the impact of the pest on the production of values in a natural resource system. The development of optimum forest pest management strategy requires a thorough integration of the results of studies in population dynamics, forest pest control, forest pest impact, and the dynamics of the production of resource values.

Tables 5 through 8 show some interesting effects of using the sterile male control procedure in the exponential population system. It is clear that the system stabilizes at a lower pest density when fewer sterile males are used than are needed for extermination of the population and that net benefits increase remarkably with the use of large numbers of sterile males. One wonders whether there is an optimal trajectory towards extermination of the population using the same total number of sterile males. Perhaps using moderate numbers when the population is high and large numbers later would be better than the same number in each generation, or perhaps the converse would be best.

Table 9 shows the results of one attempt to explore this question. They reveal a typical result -- one can choose an optimal control procedure on the basis of obtaining a desired system state most rapidly, or on the basis of least net cost, and the two bases seldom provide the same result. These, however, are among topics for another discussion.

Copies of the program are available upon request from:

Forest Insect and Disease Laboratory

Northeastern Forest Experiment Station

151 Sanford Street

Hamden, Connecticut 06514

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Produced insect and Disease Labourt Jacob

North-astern Forest Experiment Starlog

151 Sanford Street

lande , Commecticut 06514

SELECT A POPULATION MODEL OS,LS,EX: >os

SELECT A CONTROL SYSTEM - 14 OR SM: >in

ENTER NUMBER OF GENERATIONS: >20

ENTER LOSO % LOSS OF PUSECTICIDE: >.2 2

ENTER LOSD % LOSS OF COST OF A UNIT OF CONTROL: >1 5

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SPECIFY PROPERT MODIALITY 10 ALL GENERATIONS: >75

SPECIFY DAMAGE FUNCTION NUMBER AND VALUE OF 100% OF COMPLETS NAMAGE OCCURS: >5 7

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YOU PRODUCED AN AVERAGE DENSITY UNICH MAS 3.52% OF THAT OF THE PROPURATION, AND 25.00% OF THAT OF THE YEAR TO YEAR COMTECLED POPULATION.
YOU USED A TOTAL OF . 9.44 UNITS OF NATERIAL AT A TOTAL COST OF 67.22
THE SUM OF YOUR SMORT TERM GAINS MAS: 119.84 FOR A MET SEMEFIT OF: 52.62
THE SUM OF YOUR LONG TERM GAINS MAS: 298.17 FOR A MET SEMEFIT OF: 230.95

FINISHED?>n

ENTER LIBSO A LB95 OF THEEDTTOTHE: >2 2
ENTER FIXED AND VARIABLE COST OF A UNIT OF CONTROL: >1 5

"HILL YOU AREA UNITALITY IN ALL SEMERATIONS: >35
SPECIFY DANAGE EURCTION NUMBER AND VALUE OF 100% DANAGE: >4 50
SPECIFY DANAGE EURCTION NUMBER AND VALUE OF 100% DANAGE: >4 50
SPECIFY MUNICERS IN FIRST THREE GENERATIONS: >500 1000 25000 SELECT A POPULATION MODEL OS, LG, EX: >os SELECT A CONTROL SYSTEM - 14 OR SM: >in ENTER NUMBER OF GENERATIONS: >20

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YOU PRODUCED AN AVERAGE DENSITY WHICH WAS 1.47% OF THAT OF THE UNDISTURSED GODULATION, AND 15.00% OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATION.
YOU USED A TOTAL OF 15.53 UNITS OF HATERIAL AT A TOTAL COST OF 27.65
THE SUM OF YOUR SHORT TERM GAINS WAS: 342.90 FOR A NET DEMERIT OF: 245.25 FINISHED?>n

SELECT A POPULATION MODEL OS,LG,EX: >os
SELECT A CONTROL SYSTEM IN OR SH: >in
ENTER HUNDER OF SEMERATIONS: >20
ENTER FIXED AND VARIABLE CONTROL: >2 2
ENTER FIXED AND VARIABLE CONTROL IN EACH GENERATIONS: >1 5
WILL YOU APPLY UNIQUE CONTROL IN EACH GENERATIONS >n
SPECIFY PERCENT MORTALITY IN ALL GENERATIONS: >95
SPECIFY DAMAGE FUNCTION NUMBER AND VALUE OF 100% DAMAGE: >4 50
ENTER LOGS OF PEST DENSITIES AT WHICH 10% AND 90% OF COMPLETE DAMAGE OCCURS: >5 7
SPECIFY MUNDERS IN FIRST THREE GENERATIONS: >500 1000 25000

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252295.87	81.	4594.	53537.	38937.	2020.	36.	در،	<u></u>	17.	855.	23534.	59665.	8570.	197.	5.	jà	5.	155.	. 6843.	53442.	* [" * *
27.9	0.01	0.56	5.77	4.32	0.27	0.01	0.00	0.00	0.00		2.72	6.36		0.	0.00	.00	.00	0.02	0.85	5.76	**************************************
0.04	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	* DOSAGE
220.0	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	. 11.00	11.00	*
125.9	0.10	4.19	22.93		2.10	0.05	0.00		0.02	0.95	15.02	23.92			0.01				6.09	22.91	***********
-94.08	-10.90	-6.81	11.93	8.87	-8.90	-10.95	-11.00	-11.00	-10.38	-10.05	4.02	12.92	-3.69	-10.76	-10.99	-11.00	-10.99	-10.81	-4.91	11.91	TERM 1 SENEFITI
373.1	42.38	0	29.73	0.31	-0.04	0.02	0.09	2.40	31,95	45.97	40.67	86.98	-0.20	0.02	0.04	0.54	14.98	43.44	44.84	22.91	OF LONG
ы з 55 з 5 з 1 з	• co	10	73	0	40	60	91	0.0	U	97	67	02	20	8	96	0.00	3.98	44	3.84	1.91	BENEFIT IG
,	20	14	01	17	10	15	14	13	12	11	10	9	00	7	01	5	4:-	V	2	j	* G * E * Z

YOU PRODUCED AN AVERAGE DENSITY WHICH WAS 0.403 OF THAT OF THE UNDISTURSED POPULATION, AND 5.003 OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATION.
YOU USED A TOTAL OF 40.00 UNITS OF MATERIAL AT A TOTAL COST OF 220.00
THE SUN OF YOUR SHORT TERM GAINS WAS: 125.02 FOR A NET SENEFIT OF: -94.08
THE SUN OF YOUR LONG TERM GAINS WAS: 373.05 FOR A NET SENEFIT OF: 153.05

FINISHED?>n

SELECT A POPULATION MODEL- OS, LG, EX: >os SPECIFY DAMAGE FUNCTION MUNICER AND MALUE OF 100% DAMAGE: >4 50 PEST DEMINITIES AT MULCH 10% AND 90% OF COMPLETE DAMAGE OCCURS: >5 7 HIER LOSO & LOSS OF INSECTICIDE: >.2 2
HIER FINES NID VARIABLE COST OF A UNIT OF CONTROL: >1.5
LL YOU APPLY UNIQUE CONTROL IN EACH GENERATION? >Y

2.17% OF THAT OF THE UNDISTURBED POPULATION. 1355157.0 142. 1.98 12.88

27.35

62414288.

774.

2482911:0

197.

YOU PROPUGED AN AVERAGE DENSITY UNICH MAS 2.17% OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATIONS.
AND S4.58% OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATIONS.
YOU USED A TOTAL OF 1.98 UNITS OF MATERIAL AT A TOTAL COS SUM OF YOUR LONG TERM GAINS WAS: 27.35 FOR A NET BENEFIT OF: 315.79 FOR A HET SEMEFIT OF: A TOTAL COST OF

SELECT A POPULATION HODEL- OS,LG,EX: >ex

SELECT A CONTROL SYSTEH- IN OR SN: >sm

ENTER HUMBER OF GENERATIONS: >10

ENTER FIXED AND VALABLE COST OF A UNIT OF CONTROL: >5 .001

WILL YOU APPLY UNIQUE CONTROL IN EACH GENERATION? >n

WILL YOU USE A CONSTANT NUMBER OF STERILE MALES? >y

SPECIFY NUMBER OF STERILE MALES TO BE RELEASED EACH GEM: >1000

SPECIFY DAMAGE FUNCTION NUMBER AND VALUE OF 100% DAMAGE: >4 500

ENTER LOGS OF PEST DENSITIES AT WHICH 10% AND 90% OF COMPLETE DAMAGE OCCURS: >3 5

SPECIFY NUMBERS IN FIRST THREE GENERATIONS: >500 500 100000

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NA CHOROCOR	1000000.0	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	DENSITY DAMAG	
AVERACE	500.	90.0										DAITAGE	
SVE HOTHER ALIENAE BENEFIC CEORGOOD NO.	998130.00	93795. 90										EXPECTED VI	
	900.	90.0 1.										WITH CONTROL CONTROL RATE AGE RATE ************************************	
97.862 OF THAT OF THE UNDISTURBED POPULATION.	9705	96	96	96	000	96	36	96	.96	1.96	. 96	* *	
T 10 TAILT	970572.44				•	Ť				97256.	Ť	ACTUAL 005A5E	
Storing Bill	808	89.81 10	89.81 10	89.81 10	89.81 10	89.81 10	29.81 10	83.81 10	89.01 10	89.81 10	89.83 10	DAIIAGE	
TURBED P	.100E 0560.00	00.	000.	000.	,000	000.	000.	000.	000.	1000.	000.	000AGE	
OPULATION	60.00	6.00	6.00	6.00	0.00	5.00	6,00	0.00	0.00	6.00	6.00	* * COST	
	8.597	0.86	0.86	0.86	0.86	0 0 0	0.86	0.86	•	0.86	0.86	SHORT GAIN	
	-51.40	-5. I4	-5.14	-5.14	-5.14	-5.14	-5.14					* [1]	
	9.379	0.95	0.05	0 ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° °		0.0						*** TON	
	-50.62	-5.05 LU	- U. O. U.	- 5. O5	י ני	10.00	-5.05	10° 00	15.05	-5.00 2	-5,14, 1	* SELECTION ** ** ** ** ** ** ** ** ** ** ** ** **	

AND 98.04% OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATION.
YOU USED A TOTAL OF 10000.00 UNITS OF HATERIAL AT A TOTAL COST OF
THE SUN OF YOUR SHORT TERM GAINS WAS:
THE SUN OF YOUR LONG TERM GAINS WAS:
9.38 FOR A HET BENEFIT OF:
FINISHED?>n

SELECT A POPULATION HODEL- OS,LG,EX: >cx

SELECT A CONTROL SYSTEN- IN OR SH: >sm

ENTER HUNDER OF GENERATIONS: >10

ENTER FIXED AND VARIABLE COST OF A UNIT OF CONTROL: >5 .001

WILL YOU APPLY UNIQUE CONTROL IN EACH GENERATION? >n

WILL YOU USE A CONSTANT NUMBER OF STERILE HALES? >y

MILL YOU USE A CONSTANT NUMBER OF STERILE HALES? >y

SPECIFY NUMBER OF STERILE HALES TO BE RELEASED EACH GEN: >10000

SPECIFY DAHAGE FUNCTION NUMBER AND VALUE OF 100° DAHAGE: >4 500

ENTER LOGS OF PEST DENSITIES AT UNION 100° AND 500 OF COMPLETE DAHAGE OCCURS: >3 5

ENTER LOGS OF PEST DENSITIES AT UNION 100° AND 500 100000

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900.	90.0	0.00	90.0	90.0	90.0	90.0	90.0	90.0	90.0	0.06	*****	TROL (
964591.44	**************************************	. 69356	95870.	95873.	95881.	95908.	25990.	96248.	97083.	100000.	" 斯斯斯斯斯斯尔尔尔斯斯斯斯	DENSITY IDAMAGE!
897.	* 89 . 5	89.6	0.00	89.5	39.6	9 63	89.6	30.7	89.7	90.0	***	D WITH
7	17.26	17.26	17.26	17.26	17.26	17.26	17.24	17.20	17.08	16.67	特外不不不安格的	WITH CONTROL
796941.81	**********	79322.	79322.	79325.	79333.	79359.	79438.	79689.	.66403	83333.	· · · · · · · · · · · · · · · · · · ·	ACTUAL ACTUAL
379.	******	87.83	87.83	87.83	87.83	87.83	87.84	87.87	87.93	88.32	*****	DAHAGE TAU
.100E 06150.0	*****	. 100E 05	.100E 05	1005 05	100E	.100E 05	100E	1005	100E	.100E 05	*****	POSAGE
6150.0	******	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	******	COST
89.32	**************************************	9.02		9.02	9.02	9.02	9.00		000	8,39	*****	SHORT
89.09	*****	, U	· ·	5.98	10.98	10.00	-6.00	+0.04	-6.1/	-0.61	*****	TERM BENEFIT
105.1	*******	10.80	10.86	10.86	10.85	10.84	67.0T	TO.00	ZT . O.T.	, co	**************************************	OF LONG
-44.92	在	1 4 4 4 1	- t- t-	- t - T t /	10 th th	-4. LC	-4.21 4	14.0/	7 20 4-		***************************************	LONG TÉRM BENEFIT 1954

YOU PRODUCED AN AVERAGE DEMSITY WHICH WAS 79.893 OF THAT OF THE UND AND 52.833 OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATION.
YOU USED A TOTAL OF '1000000.00 UNITS OF MATERIAL AT A TOTAL COST OF THE SUN OF YOUR SHORT TERM GAINS WAS:

79.893 OF THAT OF THE UND AVERAGE TO YEAR OF THE UND TOTAL COST OF THE SUN OF YOUR SHORT TERM GAINS WAS:

105.08 FOR A MET BEMEFIT OF: 79.893 OF THAT OF THE UNDISTURBED POPULATION, -60.68

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ED 6

SELECT A POPULATION HODEL- OS,LG,EX: >ox

SELECT A CONTROL SYSTEH- IM OR SM: >sm

ENTER NUMBER OF GENERATIONS: >10

ENTER FIXED AND VARIABLE COST OF A UNIT OF CONTROL: >5 .001

UNIL YOU APPLY UNIQUE CONTROL IN EACH GENERATION? >n

HILL YOU USE A CONSTANT MUMBER OF STERILE HALES? >y

SPECIFY MUMBER OF STERILE HALES TO BE RELEASED EACH GEN: >25000

SPECIFY DAMAGE FUNCTION MUMBER AND VALUE OF 100% DAMAGE: >4 500

ENTER LOGS OF PEST DENSITIES AT WHICH 10% AND 90% OF COMPLETE DAMAGE OCCURS: >3 5

ENTER LOGS OF PEST DENSITIES AT WHICH 10% AND 90% OF COMPLETE DAMAGE OCCURS: >3 5

ENTER LOGS OF PEST DENSITIES AT WHICH 10% AND 90% OF COMPLETE DAMAGE OCCURS: >3 5

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1000000.0	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	OENSITY IDAMAGE
9000 ***	00.0	20.0	90.0	90.0	90.0	00.0	30.0	90.0	90.0	90.0	TROL
820273.87	74879.	75432.	76231.	77177.	78394.	20004.	82213.	. 85414.	90481.	1000000.0	EXPECTED DENSITY DAMAGE
1 1 2 3 3 4 1 2 3 4 1 2 3 4 1 4 1 4 1 4 1 4 1 4 1 4 1 4 1 4 1 4	87.2	87.3	87.4	87.5	87.7	87.9	30.2	00 00 00	29.1	20.0	WHASE
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	40.04		39.61	39.32		38.40	.37.82	36.92	35.59	33.53	WITH CONTROL
510213.07	*35844	45405.	46036.	46834.	47866.	40234.	51122.	53876.	58277.	. 06067.	ACTUAL ACTUAL AR***********************************
824.	50.74	0.03						83.30	84.32	85.94	*******
.250E 06300.0	250E 05	.250E 05	.250E 05						. 250E 05	.250E 05	* DOSAGE - * *
00.0	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	* COST *
284.9	52.44	32.04		30.94	30.18	29.22	27.98	26.51	23.95	20.30	SHORT .
-15.09	111.7	2.04	1.54	0.94	0. I.8	-0.78	-2.02	-5.69	-6.05	-9.70	VALUE OF TERM GA
380.0	46.51	54.54	94.44	43.21	41.65	59.65	5/.0#	55.50	28.42	20.30	**************************************
80.03	*	1 47 1 47 1 47	14.47	13.21	LL.65	9.65	1.04	0.50	1 1 0 00	-9.70	DEREPAT GEN
	+ F	,	00	7	0	, "	1 45		1 /2	نځ و	* 10

YOU PRODUCED AN AVERAGE DENSITY WHICH MAS \$1.02% OF THAT OF THE UNDISTURGED POPULATION, AND 62.20% OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATION.

YOU USED A TOTAL OF 250000.00 UNITS OF INTERNAL AT A TOTAL COST OF 300.00
THE SUM OF YOUR SHORT TERM GAINS MAS: 284.91 FOR A MET BEMEFIT OF: 15.09
THE SUM OF YOUR LONG TERM GAINS MAS: 380.03 FOR A MET BEMEFIT OF: \$0.03

SELECT A POPULATION MODEL+ OS,LG,EX: >ex SELECT A CONTROL SYSTEM+ IN OR SH: >sm SELECT A CONTROL SYSTEM+ IN OR SH: >sm SELECT A CONTROL SYSTEM+ IN OR A UNIT OF CONTROL: >5 .001 ENTER FIXED AND VACIABLE COST OF A UNIT OF CONTROL: >5 .001 WILL YOU APPLY OF A CONSTANT NUMBER OF STERILE MALES? >y WILL YOU USE A CONSTANT NUMBER OF STERILE MALES? >y SPECIFY NUMBER OF STERILE HALES TO DE RELEASED EACH GEM: >50000 SPECIFY DAMAGE FUNCTION HUMBER AND VALUE OF 1005 DAMAGE: >4 500 SPECIFY DAMAGE FUNCTION HUMBER AND VALUE OF 1005 DAMAGE OCCURS: >3 5 SPECIFY NUMBERS IN FIRST THREE GENERATIONS: >500 500 100000

N N		10	တ	တ	7	S	S	4	S	2	p.ed.	**	052		
1000000.0	****	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	100000.	**************	DENSITY DANAGE		TOGEROOF THOSE TO SE
900.	*****	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	0.00	90.0	*****	DATTAGE!		1001
357379.94	********	0.	70.	1690.	8595	20705.	34821.	450055	63376.	79057.	100000.	*************	DENSITY DAMAGE	Calbadka	
551.	***	0.0	0.9	15.5	46.4	66.7	76.7	82.0	85.3	87.8	90.0	每不许不等等	ALIAGE !		5.7
	*******	100.00	99.93	98,34	92.09	82.85	74.17	67.03	61.21	ភភ. ខភ	50.00	*****	RATE	CONTROL	VITH CONTROL
138893.12	********	0.	0.	28.	.039	3552.	* 1668	16150.	24585.	34005.	50000.	1. 脊锋等跨路外外等不分分		(=
373.	斯特洛尔洛斯姆斯	0.00	0.00	0.37			47.47	61.24	70.23	76.73	82.23	****	DAMAGE	ACTUAL	
.500E 06550.0	********	.500E 05		.500E 05	(11		* 200E 02				.500E 05	安年本年本本 本 本 本 本 本	DENSITY DAMAGE DOSAGE		
550.0	****	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00	*****	COST		
893.5	将将将将外将	0.01	4.56	75.63	196.25	T9.6T	146.0b	T6.50T	75.57	55.54	38.57	*****		SHORT	
343.5	安本路子谷子谷子子	-54.99	-50.64	20.63	74T.25	18.241	00 10		20.57	10.04	-16.43	非教育的人名英格特的	BENEFITI	TERM	VALUE
2637.	****	450.00	450.00	71.844	07.474	014.00	712.04	140.00	100	00.07	38.57	*****	GAIN I	LONG	90
2087.	本水水水水水水水水水水水水水水水水水水水	010.00 E	100 to 000	305.1/ 8		700.00			20.04	7 / 6 - 7 7		3	BEHEFIT IGET	LONG TERM	

YOU PRODUCED AN AVERAGE DENSITY WHICH WAS 13.89% OF THAT OF THE UNDISTURBED POPULATION, AND 38.86% OF THAT OF THE YEAR TO YEAR COMTROLLED POPULATION.

YOU USED A TOTAL OF 500000.00 UNITS OF MATERIAL AT A TOTAL COST OF 550.00
THE SUN OF YOUR SHORT TERM GAINS WAS: 893.52 FOR A MET BENEFIT OF: 343.52
THE SUN OF YOUR LONG TERM GAINS WAS: 2637.01 FOR A MET BENEFIT OF: 2087.01
FINISHED??n

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SELECT A POPULATION HOPEL- OS,LG,EX: >ex
SELECT A CONTROL SYSTEM- IN OR SH: >sm
SELECT A CONTROL SYSTEM- IN OR SH: >sm
SELECT A CONTROL SYSTEM- IN OR SH: >sm
SHIER HUNDER OF GENERATIONS: >10
SHIER FIXED AND VARIABLE CONTROL IN EACH GENERATION? >y
WILL YOU APPLY UNIQUE CONTROL IN EACH GENERATION? >y
WILL YOU SPECIFY HUNDERS OF STERILE HALES? (NOT 3 MORTALITY): >y
SPECIFY DAMAGE FUNCTION HUMBER AND VALUE OF 1003 DAMAGE: >4 500
SPECIFY DAMAGE FUNCTION HUMBER AND VALUE OF 1003 OF COMPLETE DAMAGE OCCURS: >3 5
SPECIFY HUNDERS IN FIRST THREE GENERATIONS: >500 500 100000

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100000. 90.0	1000000. 90.0	100000. 90.0	100000. 90.0	100000. 90.0	100000. 90.0	100000. 90.0	100000. 90.0	100000. 90.0	-
90.0	30.0	90.0	0.06	90.0	90.0	90.0	90.0	90.0	TROL
0.	0.	0.	12.	309.	2787.	18954.	61401.	100000.	EXPECTED DENSITY DAI
0. 0.0 >2000	0.0 >0 -0.0	0.0 >3000	0.2 >5000	3.5 >10000	22.8 >30000	18954. 54.8 >150000	61401. 85.0 >200000 86.69	1000000. 90.0 >100000	WITH CONTROL CONTROL CONTROL CONTROL CONTROL RATE
	. 0.	0.	0.	5.	124.	1126.	8171.	33333.	VALUE OF COST SHORT TERM LONG TERM DENSITY DAMASE DOSAGE COST GAIN SENEFIT GENERAL GENERAL GENERAL COST GAIN COST C
	0.00.0	0.00	0.00	0.07	1.49	11.07	45.20	75.93	OVIIVE I
	.0	0.00 .300E 04	0.00 .5005 04	0.07 .100E 05	1.49 .300E 05	11.07 .150E 06	45.20 .200E 06	33333. 75.93 .100E 06	**************************************
	0.0	4 8.00	10.00	5 15.00	5 35.00	6 155.00	6 205.00	6 105.00	**************************************
	0	00	0	0	0		0	0	* GA S
	0.0	0.00	0.80	17.14	106.59	268.64	198.84	70.35	SHORT TERM
	0.0	-8.00	-9.20	2.14	71.59	113.64	-6.16	-34.65	VALUE OF ************************************
	450.00	450.00	450.00	449.67	442.55	394.66	224.02	70.35	**************
	450.00	442.00	440.00	434.67	407.55	233.66	19.02	-34.65	**************************************
	00	7	9	UI	4	3	2	۳	* 25

800000.00 720. 183461.44

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POPULATION EXTERMINATED

YOU PRODUCED AN AVERAGE DENSITY WHICH WAS 5.34% OF THAT OF THE UND AND 23.31% OF THAT OF THE YEAR TO YEAR CONTROLLED POPULATION.
YOU USED A TOTAL OF 498000.00 UNITS OF MATERIAL AT A TOTAL COST OF THE SUN OF YOUR SHORT TERM GAINS WAS: 662.36 FOR A MET BEMEFIT OF: THE SUN OF YOUR LONG TERM GAINS WAS: 2931.24 FOR A MET BEMEFIT OF: 266. 5.34% OF THAT OF THE UNDISTURBED POPULATION, 42758.875 134. .498E 06533.0 533.00 129.36 2398.24

662.4

129.4

2931.



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